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8. From the Author
July 15. 1873 —
ON THE

COMPOSITION AND ORIGIN

OF THE

WATERS OF A SALT SPRING

IN

HUEL SETON MINE.

BY

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WITH A PLATE.

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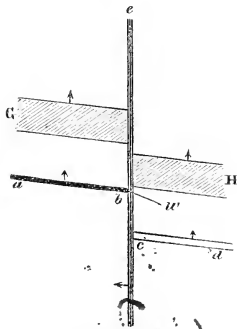
ON THE
COMPOSITION AND ORIGIN OF THE WATERS
OF
A SALT SPRING IN HUEL SETON MINE,
WITH
A CHEMICAL AND MICROSCOPICAL EXAMINATION
OF CERTAIN ROCKS IN ITS VICINITY.

HUEL SETON Copper-mine is situated about one mile north-east of the town of Camborne, Cornwall, and is distant from the sea, on the north coast, a little more than three miles. Its position will be readily understood by the aid of the accompanying skeleton map (Plate I.) of the district, traced from that of the Geological Survey.

The workings of Huel Seton are entirely in "killas," or clay-slate; and the saline waters issue at the rate of 50 gallons per minute, and at a temperature of 92° F., from the eastern fore-breast of the 160-fathom level†. This has intersected a fault or cross-course, which can be traced in a northerly direction to the sea. The temperature of the level from the end of which the water issues, like that of the water itself, is 92° F.

The lode *ab, cd*, fig. 1, which is not well defined, and is frequently a mere narrow fissure in the clay-slate, has been driven on to its point of intersection *b* with the cross-course *ef*, and is believed to have been thrown in a southerly direction from *b* to *c*. A dyke of porphyry, *GH*, 40 feet in width, courses parallel with the lode at a distance of a few fathoms to the north; but its intersection with the cross-course not having been seen, it is not known whether any throw or dislocation actually takes place at this point, as

Fig. 1.



* Read before the Royal Society, January 30, 1873.

† My attention was first directed to the discovery of this spring by Mr.

shown in the sketch; the direction of the dip is in each case indicated by an arrow. The water which issues from the point *w* was collected and brought to the surface in carefully cleaned stoneware jars.

The following results, in grammes per litre and grains per gallon, were obtained by analysis.

Mineral Water from Huel Seton.

Solid matter 14·3658 grammes per litre, or 1005·61 grains per gallon. Sp. gr. = 1·0123.

Analytical Results.

	Grammes per litre.		Grains per gallon.	
	I.	II.	I.	II.
Carbonic acid.....	·0795	·0786	5·56	5·50
Sulphuric acid ...	·0178	·0177	1·25	1·24
Silica	·0270	·0280	1·89	1·96
Chlorine	9·1728	9·1662	642·10	641·63
Bromine	trace	trace	trace	trace
Alumina	·3456	·3460	24·19	24·22
Ferric oxide	·0031	·0033	·22	·23
Manganese	trace	trace	trace	trace
Copper	minute trace	minute trace	minute trace	minute trace
Lime	3·4795	3·4963	243·56	244·74
Magnesia	·0721	·0710	5·05	4·97
Alkaline chlorides.	6·4920	6·4626	454·44	452·38
Potassium	·0832	·0835	5·82	5·84
Cæsium*	trace	trace	trace	trace
Sodium	2·2977	2·2885	160·84	160·19
Lithium	·0805	·0794	5·63	5·56
Ammonia	trace	trace	trace	trace
Nitric acid	trace	trace	trace	trace

W. J. Henwood, F.R.S., of Penzance, who forwarded me in June last a cutting from a local newspaper headed "A Salt Spring in Huel Seton Mine." This notice states that the water had been sent to Mr. S. T. Rowe, analyst to the Truro Agricultural Association, and that an analysis had been returned "showing it to be highly impregnated with salt, salts of lime, and other chemical matter to the extent of 1072 grains to the imperial gallon." It then goes on to say, "very little iron, no copper, and no gas, beyond carbonic acid, was found by the analyst." The presence of lithium is not mentioned. A few days after the receipt of the cutting above referred to, another copy was received from Mr. R. Hunt, F.R.S., and a third from Mr. J. H. Collins, F.G.S., of Falmouth. I have also much pleasure in acknowledging my obligations to Captain R. Williams, the Manager of the Mines, for the facilities afforded by him for the collection of the water for analysis.

* The amount of cæsium appears to be very small. On adding chloride of platinum to a rather dilute solution of the alkaline chlorides obtained from this water, a slight yellow precipitate was deposited; this, after re-solution and the removal of the platinum by sulphuretted hydrogen, afforded by the spectroscopic indications of the presence of cæsium.

The foregoing results may be thus tabulated* :—

	Grammes per litre.		Grains per gallon.	
	I.	II.	I.	II.
Calcium carbonate.....	·0921	·1011	6·45	7·08
Ferrous carbonate.....	·0045	·0047	·31	·33
Manganous carbonate	trace	trace	trace	trace
Calcium sulphate	·0303	·0301	2·12	2·11
Cupric chloride.....	minute trace	minute trace	minute trace	minute trace
Calcium chloride	6·7697	6·7934	473·88	475·54
Magnesium chloride	·1712	·1686	11·98	11·80
Aluminium chloride	·9003	·9013	63·02	63·09
Potassium chloride	·0919	·0900	6·43	6·30
Cæsium chloride	trace	trace	trace	trace
Sodium chloride	5·8442	5·8210	409·09	407·47
Lithium chloride	·4888	·4820	34·22	33·74
Potassium bromide	trace	trace	trace	trace
Potassium silicate (K ² SiO ³) ..	·0693	·0719	4·85	5·03
Ammonia	trace	trace	trace	trace
Nitric acid	trace	trace	trace	trace
Total found by addition ...	14·4623	14·4641	1012·35	1012·49
Total found directly†	14·3658	.....	1005·61	.....
Free carbonic acid.....	·0373	·0323	2·61	2·26

The nature and amount of the various substances in solution in the saline waters having been determined, it was considered desirable to ascertain by analysis the composition of the principal rocks occurring in the neighbourhood of the spring. It was hoped that in this way information might be obtained respecting the sources from which some of the substances taken up by the water had been derived. It was further thought that, by comparing the composition of the rock in the immediate vicinity of the cross-course through which the heated waters issue with that of the clay-slate further removed from its influences, it might be possible to ascertain some of the effects produced by their action. In the case of each of the rocks analyzed, numerous thin sections were cut and subjected to careful microscopical examination.

“*Elvan*,” sp. gr. = 2·64.—The rock constituting the dyke G H, fig. 1, is exceedingly hard and compact, presenting the appearance of a crystalline greyish matrix, enclosing numerous well-defined crystals of flesh-coloured orthoclase; a specimen of this rock afforded by analysis the following results :—

* As the state of combination in which the various substances present in mineral waters exist cannot be accurately determined, the system of grouping adopted in the Table must to some extent be regarded as arbitrary.

† The difference between the amount of total solid contents found directly and that obtained by the addition of constituents, is doubtless partly due to the partial decomposition of aluminium and magnesium chlorides at the temperature (160° C.) at which the drying of the residue was effected.

	I.	II.
Water*	1·53	1·56
Silica	70·76	70·85
Alumina	16·78	16·86
Ferrous oxide	2·44	2·50
Manganous oxide	1·24	1·18
Sulphur	trace	trace
Lime	1·23	1·21
Magnesia	1·55	1·52
Potassa	3·08	3·20
Soda	·85	·92
	<hr/> 99·46	<hr/> 99·80

Under the microscope this rock is seen to consist of a felsitic base containing crystals of orthoclase. The base is composed of highly altered felspar, pseudomorphs, apparently after hornblende, and numerous sphærolites exhibiting a radial structure. These sphærolitic bodies are not terminated by sharp outlines, but become gradually blended with the surrounding base; their radial structure, however, is perfectly defined, particularly when examined by polarized light. There is a green floeculent substance disseminated throughout the base; and many small patches of quartz are observed, which, by polarized light, appear to break up into granules. There are also prisms of a green colour, which are apparently altered hornblende; in a few cases one portion of a crystal is seen to be composed of some hornblendic mineral, while the remainder has been replaced by felspar. In some of the sections examined minute spots and microscopic crystals of iron pyrites were observed.

This rock would be generally described as a porphyry; but Mr. S. Allport, who at my request had the kindness to cut and examine a section of it, considers its composition would be better indicated by the name Porphyritic Felsite. It has, however, undergone a considerable amount of alteration; and although the larger crystals of orthoclase are for the most part unchanged, the smaller ones are almost without exception pseudomorphs.

Granite from Carn Brea, sp. gr. = 2·64.—The Carn Brea Hill, about a mile south-east of Huel Seton, is composed of a rather coarse-grained granite, in which the proportion of quartz is generally large; the felspar sometimes occurs in crystals of considerable size. It contains two varieties of mica, the one black (lepidomelane?), and the other white or slightly tinged with pink; the latter appears to be a variety of lepidolite.

The chemical composition of this granite was found to be as follows:—

* Of which ·19 was lost in the water-bath.

	I.	II.
Water*	1·20	1·26
Silica	74·62	74·76
Alumina	16·29	16·13
Ferrous oxide	1·18	1·15
Ferric oxide	trace	trace
Manganous oxide . .	·55	·62
Lime	·30	·26
Magnesia	·50	·46
Potassa	3·54	3·74
Soda	1·24	1·13
Lithia	·11	·09
	<hr/> 99·53	<hr/> 99·60

A microscopical examination of this rock does not afford much information not to be obtained by a close inspection of hand-specimens. A large proportion of the felspar is seen to be monoclinic; but triclinic felspar is also present in considerable quantity. The outlines of the crystals are not in all cases sharply defined, and they are sometimes rendered slightly cloudy by some flocculent chloritic mineral. Two varieties of mica are distinctly visible, and occur in both quartz and felspar, together with a little tourmaline. The quartz is much fissured, the sides of the cracks being apparently coated by ferric oxide; it contains numerous fluid-cavities enclosing bubbles, which in some of the smaller ones are observed to be in constant motion.

Clay-slate &c.—In those portions of the mine situated at a distance from the cross-course, the “killas” is a very hard clay-slate of a grey colour. Cleavage is in the majority of cases to some extent obliterated; no trace of crystalline structure can be detected; and the rock, in addition to being traversed by numerous strings of white quartz, is thickly studded with minute spots and crystals of iron pyrites. Sp. gr. = 2·73.

In the immediate vicinity of the fault, which appears to furnish a channel for the passage of the saline waters, the slate has become much altered, is of a dark green colour, consists to a great extent of minute acicular crystals, with their longer axes parallel to the planes of cleavage, and in many cases closely resembles some varieties of serpentine. Crystals of chlorite are found in the joints of cleavage. It also exhibits many of those highly polished surfaces so frequently met with in serpentineous rocks. Sp. gr. = 2·69.

By analysis these rocks were respectively found to have the following compositions:—

* Of which ·34 was lost in the water-bath.

	Unaltered clay-slate.		Rock in vicinity of cross-course.	
	I.	II.	I.	II.
Water*	3.13 <i>a</i>	3.10	6.87 <i>b</i>	6.84
Silica	67.78	67.87	45.85	45.97
Alumina	9.60	9.52	16.60	16.78
Ferrous oxide.....	5.09	4.96	10.59	10.72
Ferric oxide	trace	trace	trace	trace
Manganous oxide..	1.27	1.14	1.16	1.12
Lime	2.62	2.54	2.68	2.68
Magnesia	3.48	3.37	6.94	6.87
Potassa	2.45	2.30	.92	.78
Lithia .....	.....	.....	trace	trace
Soda	4.46	4.32	5.64	5.53
Sulphur .....	.36 } = .68	.32 } = .60	.78 } = .146	.80 } = .150
Iron .....	.32 } FeS ²	.28 } FeS ²	.68 } FeS ²	.70 } FeS ²
Sulphuric acid ...	.....	.....	.76	.74
Chlorine .....	.....	.....	trace	trace
	100.56	99.72	99.47	99.53

Thin sections of the clay-slate situated at a distance from the cross-course are seen under the microscope to consist of bands of transparent granular quartz alternating with layers of similar quartz, through which a transparent, dichroic, pinkish-brown mineral is thickly disseminated in the form of imperfectly defined elongated crystals. The outline of these, of which the dimensions of the largest are $\frac{3}{1000} \times \frac{1}{1000}$ of an inch, is so irregular, and they are so crowded and interlaced, that it is impossible to determine their crystalline form; they are, however, believed to be hornblende.

When examined with an inch objective, the mass, in addition to numerous crystalline bodies, appears to be full of a brown dust, arranged in approximately parallel bands, which much diminish the transparency of those portions of the sections in which it most plentifully occurs. By the aid of a power magnifying 510 diameters, this dust is resolved into crystalline tufts of a dark colour and hornblendic appearance. Dendritic patches and crystals of iron pyrites are disseminated throughout the rock; and some of the veins by which it is traversed enclose well-defined crystals of both chlorite and hornblende.

The altered rock in the immediate vicinity of the cross-course is seen to be composed of closely matted prisms of brown hornblende enclosing pale green crystals of actinolite. It also contains a few crystals of quartz, and iron pyrites in the form of minute cubes.

* *a* lost .94 per cent. in the water-bath, and *b* 1.55 per cent.

Source whence the mineral waters of Huel Seton are probably derived.—Before attempting to account for the presence of the mineral constituents found in these waters, it will be necessary to consider the bearing and importance of the following facts :—

(a) The average elevation of the surface of the mine is about 300 ft. above the sea ; and the 160-fathom level, being 960 feet below the adit or drainage-tunnel and 1080 feet from the surface, is consequently much beneath low-water mark.

(b) The cross-course, shown in the accompanying geological map, may, as has been already stated, be traced for a distance of three miles to the coast, and apparently forms the channel through which the saline waters effect an entrance into the workings.

(c) The water contains a very large proportion of chloride of sodium.

(d) Similar springs of hot saline water were met with, below the level of the sea, in the neighbouring mines of North Roskear and North Crofty, both situated on the same cross-course. These waters have not been analyzed.

(e) A hot spring yielding waters possessing the same general characteristics as those from Huel Seton, formerly issued at the Huel Clifford Mines in the 230-fathom level, or at a depth of 1320 feet below the sea. It will be seen, by referring to the Map, that in this case a well-defined cross-course can be continuously traced in a north-westerly direction from the immediate vicinity of the spring to the sea at Tobban Cove*.

* These mines are now abandoned and consequently flooded. The waters issued at a temperature of 125° F., and at the rate of 150 gallons per minute. The late Dr. W. A. Miller, who analyzed them in 1864, obtained the following results :—

Sp. gr. = 1·007. The saline constituents were found by evaporation to amount to 646·1 grains per imperial gallon, consisting of :—

Chloride of lithium	26·05
Chloride of potassium with a little chloride of cæsium	14·84
Chloride of sodium	363·61
Chloride of magnesium	8·86
Chloride of calcium	216·17
Sulphate of calcium	12·27
Silica	3·65
Oxides of iron, alumina, and manganese.	minute quantity
	<hr/> 645·45

(“ Chemical Examination of a Hot Spring in Huel Clifford, Cornwall, by Professor W. A. Miller, M.D. &c.,” Report of the Thirty-fourth Meeting of the British Association &c., held at Bath, September 1864.)

My friend, Mr. W. J. Henwood, has called my attention to the fact that so long ago as 1827 waters rich in chloride of sodium had been found in some of the Cornish mines by Mr. R. W. Fox. This gentleman says*, "In some instances I have detected common salt, particularly in the water from the bottom of the United Mines, the Consolidated Mines†, Huel Unity, and Poldice. Out of the 92 grains of residuum from the latter‡, 24 grains proved to be the muriate of soda, 52 grains the muriates of lime and magnesia, and the remainder muriatic acid with iron and sulphate of lime. The water from another part of the same mine contained $5\frac{1}{2}$ grains of common salt. All these mines are in 'killas' or primitive slate, and several miles from the sea. It may be inferred from such facts as these that the sea-water must in some places penetrate into the fissures of the earth."

Previously to discussing whether the water in question is or is not the result of infiltrations from the sea, it will be instructive to compare, by calculation, its composition with that of sea-water so diluted with distilled water as to contain the same amount of fixed constituents as that found in the Huel Seton spring§. Analyses of the waters of the German, Atlantic, and Pacific oceans agree so closely with one another as to justify the conclusion that the waters of the entire ocean have an essentially similar composition; but for the purpose of this comparison, an analysis of the waters of the Irish Sea by Messrs. T. E. Thorpe and E. H. Morton has been selected||. This analysis has been chosen, both from the circumstance of its recent date, and also because, from the geographical position of the locality whence the water was obtained, it may be regarded as fairly representing the waters of the Atlantic Ocean which wash this portion of the Cornish coast.

* Transactions of the Royal Geological Society of Cornwall, vol. iii. (1827) p. 324.

† Lately part of the Clifford Consolidated Mines.

‡ From the evaporation of a pint of water.

§ The error consequent on the assumption of the dilution being made with distilled water is not great. Four deep-mine waters recently analyzed gave an average of .42 gramme of solid matter per litre, or less than 3 per cent. of the solid contents of the water in question.

|| Ann. Chem. Pharm. clviii. pp. 122-131.

Water from the Irish Sea so diluted as to contain the same amount of solid matter per litre as the water from Huel Seton.		Mineral water from Huel Seton.
Grammes per litre (calculated).		Grammes per litre found (mean).
Chlorine	7·9070	9·1695
Bromine	·0260	trace
Sulphuric acid	·9172	·0178
Silica	·	·0275
Alumina	·	·3458
Ferric oxide	·0019	·0029
Manganese	·	trace
Copper	·	minute trace
Lime	·2441	3·4829
Magnesia	·8627	·0715
Alkaline chlorides . .	11·5393	6·4773
Potassium	·1665	·0834
Cæsium	·	trace
Lithium	·	·0800
Sodium	4·4157	2·2933
Ammonia	trace	trace
Carbonic acid	·0096	·0790
Nitric acid	·0006	trace

If the Huel Seton spring be regarded as only yielding modified and diluted sea-water, it will be found, on comparing the two columns of the foregoing Table, that the percentage of chlorine in the second has been considerably augmented, that the sulphuric acid has almost entirely disappeared, silica and alumina have been taken up, and the amount of calcium has been greatly increased, whilst magnesium has, on the contrary, been abstracted. The amount of alkaline chlorides has thereby been much reduced; but a considerable quantity of lithium has entered into solution.

It would at first appear that the presence of a much larger amount of chlorine in the waters of the saline spring than should be found in dilute sea-water holding an equal quantity of solid constituents in solution affords an argument against the probability of the Huel Seton waters having had such an origin. If, however, neglecting the smaller differences, the chlorides of calcium and aluminium in the spring-water be, on the one hand, replaced by an equal weight of chloride of sodium, and, on the other, the excess of sulphuric acid in the dilute sea-water be replaced by chlorine, making a correction for the resulting slight difference in the total weight, the amount of chlorine in the two columns will be found very nearly the same. This objection is consequently disposed of.

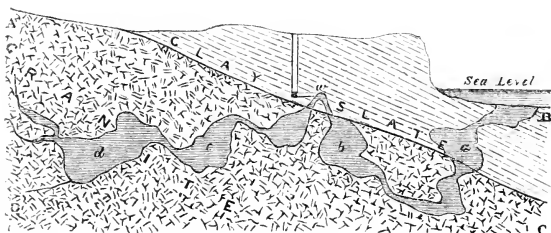
The analyses of the different rocks in the vicinity of the spring have shown that the granite only could have furnished the lithium, of which the waters have taken up a notable amount.

A consideration of the various phenomena connected with the occurrence of this and other apparently similar springs which have at different times been discovered in the district, would seem to lead to the inference that they all have some more or less direct communication with the sea, and that they are either the result of infiltration of sea-water through faults, or are true and independent sources, which, before being tapped below the sea-level, had found their way to the ocean through the faults or channels before alluded to.

It would be impossible to ascertain the precise conditions under which springs of this description have been produced; but the accompanying ideal sketch may perhaps assist in rendering intelligible what would appear, in the present state of our knowledge, a not improbable explanation of their origin.

The plane A B C D (fig. 2), being that of the cross-course, is

Fig. 2.



seen to extend through both granite and clay-slate to the sea. From the close contact of its surfaces, the presence of clay, and from other causes, this fault is supposed not to be uniformly permeable by water, which can only follow the circuitous passage, *a b c d*. In this way it penetrates to depths where reactions take place, which, although not entirely in accordance with the results of daily experience in our laboratories, can, after the investigations of M. Daubrée, M. de Sénarmont, and others, be readily understood.

By the action of sea-water on *silicates of calcium*, *silicates of sodium* and *chloride of calcium* may be produced. The *sulphate of sodium* of the sea-water will be decomposed by the *chloride of calcium*, with the production of *sulphate of calcium* and *chloride of sodium*. The decomposition of clayey matter by common salt

may produce *chloride of aluminium* and *silicates of sodium*, while the *magnesium* of the chloride of magnesium may be replaced by *calcium*; lastly, a portion of the *potassium* in the sea-water appears to have been replaced by the *lithium* of the granite.

The alteration which has taken place in slates in the vicinity of the cross-course has evidently been attended with the loss of a large percentage of its silica. In fact this appears to have been the chief chemical change effected, since, if we calculate what would be the composition of the clay-slate after the reduction of its percentage of silica to the amount contained in the altered rock, the calculated results will be found to agree very closely with the analysis of the latter. One per cent. of *lime*, however, has been exchanged for *alumina*, and about the same amount of *magnesia* has been substituted for an equivalent quantity of *potassa* and *soda*.

